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THE JOHN A. Blume EARTHQUAKE ENGINEERING CENTER

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING, STANFORD UNIVERSITY

DIRECTOR: PROFESSOR GREGORY G. DEIERLEIN
ADMINISTRATIVE ASSOCIATE/EDITOR: RACQUEL HAGEN
TELEPHONE: (650) 723-4150, FAX (650) 725-9755 WEBSITE: BLUME.STANFORD.EDU E-MAIL: EARTHQUAKE@CE.STANFORD.EDU

Blume Center Hosts Five Visiting Professors

The Blume Center is honored to have five visiting professors with us this year. **Lawrence C. Bank**, UPS Visiting Professor, is at the Blume Center on sabbatical leave from the University of Wisconsin-Madison where he is a Professor in the Department of Civil and Environmental Engineering. Prof. Bank is an expert on the use of fiber-reinforced polymer (FRP) composite materials in structural engineering. At Stanford, he is working on analysis and design procedures for non-bonded, ductile, energy absorbing, FRP strengthening systems for reinforced concrete flexural members and reinforced concrete frames, and on specifications for the design of building and bridge structures using pultruded FRP profiles. On-going research projects in Wisconsin include prefabricated FRP grids and stay-in-place forms for highway bridge decks, as well as, FRP tubular structural systems.

Yukihiro Harada is an Associate Professor in the Department of Architecture at Chiba University in Japan. He is collaborating with Prof. Greg Deierlein and Amit Kanvinde (PhD student) on an investigation of earthquake-induced fractures in steel structures, with specific application to fracture resistant design of welded connections. In addition, he his studying the seismic design of steel buildings with semi-rigid beam-column connections.

Prof. Faruk Karadogan, Istanbul Technical University (ITU), conducts experimental and theoretical research on traditional reinforced concrete (RC) and prefabricated industrial type structures. At Stanford, Prof. Karadogan is working with Prof. Helmut Krawinkler, on displacement protocols to be used at ITU for tests on prefabricated columns subjected to displacement reversals. Early experimental results from tests conducted at the ITU are being evaluated while Prof. Karadogan is in residence here. Joint research with Prof. Eduardo Miranda and Prof. Bank, on the use of bonded and unbonded FRP strips or unbonded externally placed post-tensioned elements, is being considered.

Mary Comerio is a professor of architecture at University of California Berkeley Over the course of her career, she has worked as a practicing architect, designing public buildings, market rate and affordable housing. Her research has focused on seismic design issues and risk modeling. During her sabbatical at the Blume Center, she is working on modeling downtime based on earthquake damages. This work involves quantifying the time needed for management and finance decisions along with time for design and construction. One of her case studies will review the priorities set for building repair on the Stanford campus after the Loma Prieta earthquake.

Prof. Eduardo Reinoso, UNAM Mexico, is researching the development of tools that compute the loss estimation of contents of buildings during earthquakes. He will be testing an approximate method based on the shear-flexure beam behavior to obtain an estimation of floor acceleration spectra at any structure. He is also developing analytical models to study the dynamic behavior of blocks with different overturning characteristics.

Alumni, Affiliates and Friends are encouraged to send news items about yourselves to earthquake@ce.stanford.edu for inclusion in the next newsletter.

BLUME CENTER NEWS

Ph.D. Candidate Chao Li and his wife, Jieru Zhou, welcomed their first child, Shawn, on July 20. He weighed 7lb, 1oz and was 20 inches long.

Profs. Anne Kiremidjian and **Greg Deierlein** participated in the 1st Tri-Center User Workshop in Application of Earthquake Loss Estimation Methodologies for Transportation Highway Systems, held in San Pedro, CA , June 23-25.

Prof. Kincho Law was the invited Keynote Speaker at the 2nd International Conference on Innovation in Architecture, Engineering and Construction, University of Loughborough on June 25. His speech was entitled, "Distributed Computing and Communication Technologies for AEC."

P**rof. Ronnie Borja** participated in the First Japan-US Workshop on Testing, Modeling and Simulation in Geomechanics held in Boston on June 27-29. He presented a paper on modeling and simulation of deformation bands in granular media. **Prof. Anne Kiremidjian** and **Ph.D. Candidates Krishnan Nair Kesavan** and **Dimitris Pachakis** also presented papers.

Prof. Kincho Law enjoyed a month long stay (July 1-30) as a Visiting Faculty at the Applied Computing and Mechanics Laboratory, Swiss Federal Institute of Technology, Lausanne, Switzerland.

Prof. Chuck Menun and **Ph.D. Candidate Qiang Fu** attended the Ninth International Conference on applications of Statistics and Probability in Civil Engineering (ICASP9) held July 6-9 in San Francisco. Qiang presented a paper "A system-based approach for time-variant structural reliability analysis".

Prof. Kincho Law gave a series of lectures at the IMAC Summer Lecture Series, at the Swiss Federal Institute of Technology, Lausanne, Switzerland: "Vibration-based Monitoring and Damage Assessment of Civil Structures", "Lecture on Application of Data Structures and Algorithms in Engineering", "Lecture on Gaussian Elimination (Numerical method is not only numeric)", and "Integration and Coordination of Distributed Engineering Services".

Prof. Ronnie Borja delivered a keynote speech entitled "Analysis of Deformation Bands in Geomaterials" at the Seventh US National Congress on Computational Mechanics held in Albuquerque, NM, July 27-July 31.

Prof. Anne Kiremidjian was a keynote speaker, "Assessing Uncertainties in Earthquake and Other Extreme Event Loads," at the Response of Structures to Extreme Loading Conference in Toronto, Aug. 3-6.

Prof. Anne Kiremidjian gave the C. Martin Duke Lecture at the Sixth US Conference on Lifeline Earthquake Engineering, August 10-13, 2003, Long Beach, California. The title of the lecture was "Performance Based Lifeline Earthquake Engineering". She also presented joint papers with Jim Moore, Nesrin Basoz and Meredith Williams on "GIS-Based Emergency Response System for Traffic Networks". At the same conference **PhD Candidate Dimitris Pachakis** presented a paper on Issues in the "Development of A Simulation Model for Seismic Risk of Sea Ports".

On August 11, **Prof. Anne Kiremidjian** received the C. Martin Duke Award for Excellence in Lifeline Earthquake Engineering by the American Society of Civil Engineers.

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RESEARCH SPOTLIGHT

Finite Element Model of Poro-Elasticity Suitable for Large Deformation Dynamic Analysis

Chao Li and Ronaldo I. Borja

INTRODUCTION

Porous materials are defined as materials with an internal structure. They comprise a solid phase and closed and open pores. The solid phase is usually referred to as the matrix or skeleton. The pores may be filled with one or more kinds of fluids. Soil, rock, concrete, aluminum foam, and the human cornea are some common examples of porous materials. The mechanics of porous media is of utmost interest in many disciplines such as geotechnical engineering, earthquake engineering, geophysics, petroleum engineering, biomechanics, physical chemistry, agriculture engineering and materials science.

Theory of porous media has been of great interest to researchers for a considerable time [1-7]; de Boer [8] provided a detailed historical review of its development. The motivation behind this present research is the formulation of a mathematical model characterizing the behavior of fully saturated porous media during dynamic excitation. The challenge lies in the transient behavior of this material as the solid matrix deforms. Such solid deformation is generally accompanied by transient flow of fluids through and across the open pore spaces. Furthermore, large deformation of the solid matrix gives rise to second-order geometric effects not accounted for by the linear theory. Finally, the presence of inertia loads in both the solid and fluid phases makes the solution of the coupled phenomena computationally demanding. To the knowledge of the authors there is currently no systematic way of treating geometric nonlinearity in the context of dynamic analysis of fully saturated porous media.

This research presents a mathematical framework for characterizing the response of fully saturated porous media subjected to dynamic excitation. The formulation accounts for transient fluid diffusion and finite deformation effects. A nonlinear Neo-Hookean hyperelastic constitutive model with a viscoelastic enhancement of the Kelvin solid-type is implemented. The formulation is intended to serve as a foundation for more advanced computational modeling platforms that may also account for plasticity/viscoplasticity. By using different material subroutines, the method can be used for geotechnical earthquake engineering applications and to other related problems in science and engineering.

METHODOLOGY

Two sources of nonlinearity exist in the analysis of porous continua, namely, material nonlinearity and geometric nonlinearity. The strong material nonlinearity exhibited by most soils under earthquake loading conditions is well known, and has been incorporated into many dynamic finite element codes. However, geometric nonlinearity has not received as much attention in the literature. Geometric nonlinearity could play an important role in stability analysis, liquefaction analysis and any situation where the strain level is high.

To address this problem, wave propagation and diffusion effects are coupled through a two-phase formulation based on theory of mixtures. The governing equations describing the coupling effects of the solid phase and the fluid phase are developed using a $\boldsymbol{u}$-p formulation, where $\boldsymbol{u}$ is the solid displacement, and p is the pore fluid pressure. They are derived from balance of mass and balance of linear momentum for the overall mixture and for each phase, respectively. The overall formulation is based on a Lagrangian description following the motion of the solid matrix alone. Pull-backs of all variables are made with respect to the reference configuration of the solid matrix. These field equations are then used to develop the variational forms for subsequent finite element (FE) implementation. A general nonlinear FE framework is then established and implemented in the 2D case. A hyper-(visco)elastic constitutive model is used for the solid skeleton based on invariant stress measures under superposed spatial rigid body rotations. Other material models such as those used in biomechanics, or more advanced elastoplastic soil constitutive models, can also be readily used within this FE framework. A Q9P4 (quadrilateral in displacement and bilinear in pore pressure) finite element is implemented to simulate dynamic plane strain problems in both the small and finite deformation regimes. Details of the formulation are presented in Ref. [9].

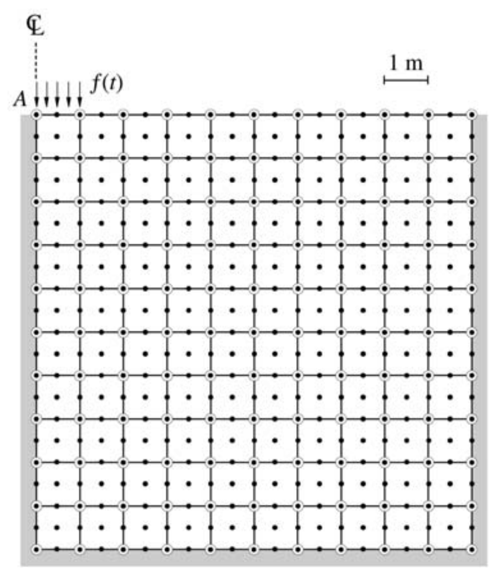

Figure 1. Mesh layout and boundary conditions.

REPRESENTATIVE NUMERICAL SIMULATION

We present a numerical example involving a strip footing subjected to harmonic loading. The objective of this example is to demonstrate the marked difference between the results obtained from small and finite deformation analyses in the dynamic regime. Complete details of this example may be found in Ref. [9].

Figure 1 shows a porous soil block supporting a footing subjected to a vertical harmonic load. The soil foundation is 20 m wide and 10 m deep; the left vertical boundary is the plane of symmetry and only the right half of the region is modeled. A flexible strip footing 2 m wide rests on the ground surface and exerts a uniform harmonic vertical load on the foundation soil. The boundary conditions on the middle line of the block are applied via horizontal rollers. The upper boundary is free. The left, right and bottom boundaries are supported and no drainage is allowed. The loading function (in MPa) is $f(t) = 3-3\cos(\omega t)$, where $\omega = 100$ rad/s. Young's modulus is $E = 14.5$ MPa, Poisson's ratio is $\nu = 0.3$, and the hydraulic conductivity K varies from 0.0001 m/s to 0.1 m/s.

Figure 2 shows the vertical displacements of node A, located directly below the center of the footing, corresponding to different values of K as predicted by the finite deformation analysis. We see that the higher the hydraulic conductivity, the higher the response amplitude and vertical displacements. Next, we show in Fig. 3 the difference in responses predicted by the finite and small deformation analyses for $K = 0.0001$ m/s. For this value of K, and, in fact, regardless of the value of the hydraulic conductivity, the vertical displacements predicted by the small deformation analyses are larger than those predicted by the finite deformation analyses. Reference [9] shows that the pore pressure responses are likewise influenced by finite deformation effects.

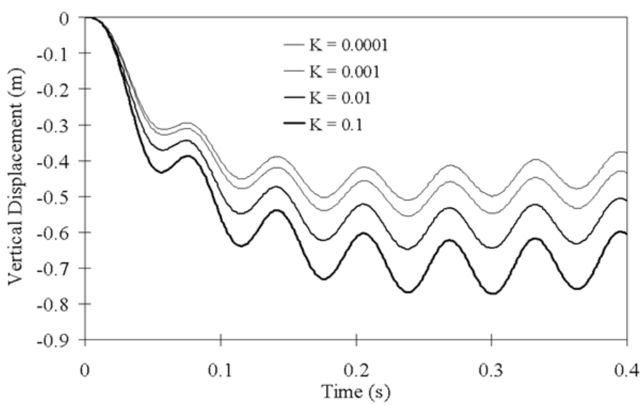

Figure 2. Finite deformation analysis: vertical displacements of node A with hydraulic conductivity varying from 0.1 m/s to 0.0001 m/s.

CLOSURE

A finite deformation formulation is necessary to accurately predict the transient response of saturated porous media at large strains. Geometrically linear models are not suitable for this purpose since they do not account for the evolving configuration and finite rotation effects. Soils undergoing liquefaction are routinely subjected to large deformation, and only by incorporating this effect, along with the irreversible deformation response, can we completely capture the liquefaction phenomena from a modeling standpoint.

ACKNOWLEDGMENTS

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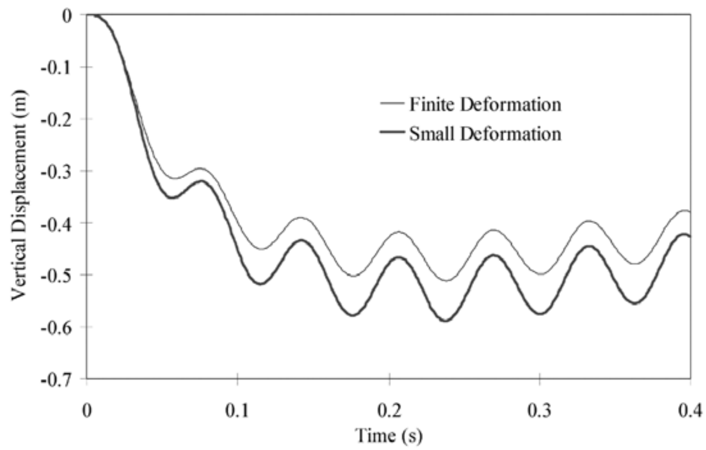

Figure 3. Comparison of vertical displacement of node A between the small and finite deformation analyses with $K = 0.0001$ m/s.

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Alumni News

Luciana R. Barrosa (MS '94, Ph.D. '99), is one of four winners of ASCE's ExCEEd New Faculty Excellence in Teaching Award for 2003. The awards were developed to recognize the efforts of ASCE members who have worked to improve civil engineering education. Luciana is a professor at Texas A&M University.

Published Papers

Kesner, KE, Billington, SL, Douglas, KS, (2003) Cyclic response of Highly Ductile Cement-based Composites,ACI Materials Journal, 100(5): 381-390.

Summer 2003 Graduates

The following students graduated with a Master's Degree in Civil and Environmental Engineering from the Structural Engineering and Geomechanics Program: **Kerrin Burgess, Laurel Chun, Wade DesRosier, Bryan Wert**. **Jeremy Legrue** received his Engineer's Degree. And **LeRoy Fitzwater** and **Shawn Kerrigan** received their Ph.D. in Civil and Environmental Engineering (Structural Engineering and Geomechanics).

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On Sept. 4, **Prof. Kincho Law** spoke on "A Parallel Sparse Direct Solver and Implementation of ParCYCLIC," at the MRCCS/NSF Summer School on High Performance Computing in Finite Element Analysis, University of Manchester, UK.

At the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE) International Conference on Partially Saturated Soils held Sept. 18-19, **Prof. Ronnie Borja** delivered a keynote speech entitled "Conservation Laws for Three-phase Partially Saturated Granular Media".

Prof. Helmut Krawinkler, along with Chris Poland, Norman Scheel, Robert Bachman and Allan Purush were inducted into the SEAOC College of Fellows during the Annual Convention at The Resort at Squaw Creek, North Lake Tahoe, on Sept. 19.

Haresh Shah to Give Blume Distinguished Lecture

Professor Emeritus Haresh Shah will give the Forth Annual John A. Blume Distinguished Lecture on January 15, 2004 at 4:15pm at the Tressider Union Oak Room at Stanford University. The title of his presentation will be "THE LAST MILE - Earthquake Risk Mitigation Assistance in Developing Countries". More information about the lecture and directions will be available on the Blume Web Site. This lecture is free and open to the public.

The John A. Blume Earthquake Engineering Center
Department of Civil & Environmental Engineering
Stanford University
Building 540, MC: 4020
Stanford CA 94305-4020